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Integration of Hydrogen Production Unit at TPP to Improve Its Efficiency

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Abstract:

As the world shifts to sustainable energy, hydrogen has gained attention as an eco-friendly energy solution. Meanwhile, managing municipal solid waste (MSW) remains a global challenge especially in developing nations. Moreover, improving the efficiency of thermal power plants has become a major focus in modern times as the traditional thermal power plants operate at sub-optimal efficiencies. This study explores incorporating an MSW gasification-based hydrogen production system into a thermal power plant (TPP), proposing a cogeneration system combining electricity and hydrogen production. A novel thermal model of the cogeneration system was formulated using CAD united cycle simulation software. The research evaluated the effects of varying morphological characteristics in MSW and the energy effects of transitioning to a cogeneration system. The findings revealed that at 75% and 25% volumetric hydrogen concentration in synthesis gas, reference fuel consumption decreased by 6.02 t/h and fuel heat utilization factor increased by 32.37% respectively, confirming enhanced energy efficiency. The findings demonstrate a viable approach to enhance TPP's efficiency while addressing waste and energy challenges.

Keywords **— Thermal power plant, Steam turbine plant, Municipal solid waste, Hydrogen, Gasification**

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I. INTRODUCTION

As the world shifts to sustainable energy, hydrogen has gained attention as an eco-friendly energy solution. The international hydrogen sector is demonstrating strong expansion, with industry forecasts predicting a 9.3% compound annual growth rate between 2024 and 2030[1]. This expansion is fueled by rising global demand for sustainable energy alternatives and hydrogen's capacity to reduce carbon emissions across multiple industries, particularly in electricity production as shown in fig. 1 below.

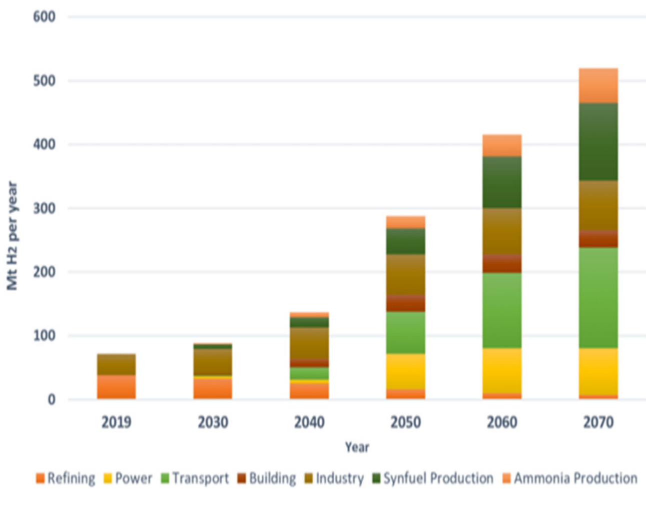

Fig. 1 Forecast of global demand for hydrogen[2]

Meanwhile, managing municipal solid waste (MSW) remains a global challenge especially in developing nations. Annual municipal solid waste generation increases astronomically as evidenced in fig. 2 below, thereby surpassing existing waste management infrastructures, leaving more than 50% of refuse unmanaged[3]. This not only leads to environmental degradation and public health risks but also represents a significant loss of potential energy resources.

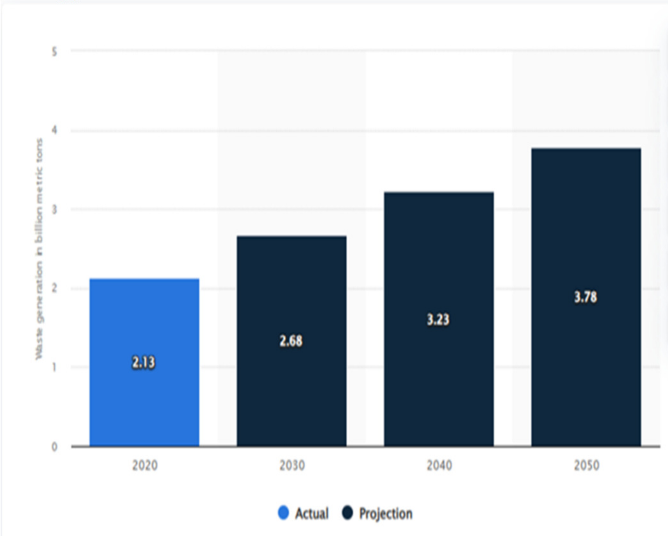

Fig. 2 Forecast of global municipal solid waste generation[4]

Furthermore, improving the efficiency of thermal power plants has become a major focus in modern times as the traditional thermal power plants operate at sub-optimal efficiencies. In an attempt to tackle these triple global challenges, this study aims to integrate a municipal solid waste gasification-based hydrogen production unit into a thermal power plant, thereby improving the TPP's efficiency and as well provide sustainable solution to the prevailing energy and waste challenges.

In order to achieve this aim, the following tasks are to be executed:

1. To model and simulate the TPP's thermal scheme
2. To develop an integration framework for integrating hydrogen production unit into the TPP's thermal scheme
3. To evaluate the effect of morphological content of the processed municipal solid waste on the key parameters of the TPP
4. To evaluate the energy effect that the integrated hydrogen production unit has on the TPP's key parameters and indexes.

Integrating hydrogen production units with existing power plants has been explored in various contexts. Siemens Energy, for example, has developed hydrogen power plants that integrated electrolyzers with gas turbines, allowing for the gradual increase of hydrogen content in the fuel mix to reduce CO2 emissions[5]. The study [6] integrated a hydrogen production unit based on methane steam reforming into CHPP plant, which resulted in 2.5% reduction in fuel consumption and improvement in fuel heat utilization coefficient by 2.57% during winter with low heating demand while in summer, fuel savings increased to 13.8% with heat utilization coefficient rising by 16.04%. Also [7] integrated a hydrogen production unit based on municipal solid waste gasification into CHPP plant with a synthesis gas cooling unit incorporated within the thermal cycle. The result showed enhanced fuel heat utilization factor (FHUF) and overall plant efficiency, irrespective of the municipal solid waste composition. The study [8] reported that the adopting Waste-Integrated Gasifier-Gas Turbine Combined Cycle (WIG-GTCC) technology to treat Municipal Solid Waste (MSW) could convert 14.61 tons/hour of MSW to combustible gas flow of 34.2 tons/hour which could be utilized to produce 19.58 MW electricity with lower emissions (0.285 kg CO2 eq/kWh) compared to traditional waste management methods, making it an environmentally favorable option.

Hydrogen has been used across various industries for a long time, with its primary applications today being oil refining, ammonia production, and methanol manufacturing. However, as the push to cut carbon emissions grows, hydrogen is now being explored for innovative applications in both traditional and emerging sectors. For instance, in steelmaking, hydrogen could replace coal and other carbon-intensive fuels essential to the process. Another promising area is concrete production, a highly emissions-heavy industry that could benefit significantly from hydrogen-based decarbonization[9]. Fig. 3 below shows the global hydrogen consumption.

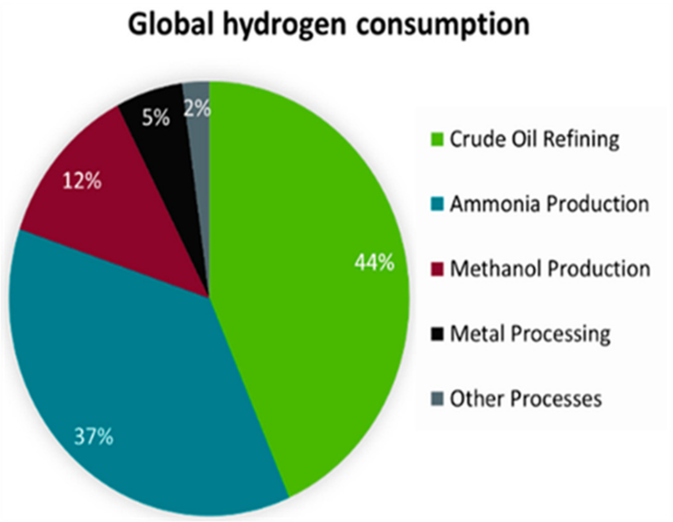

Fig. 3 Global hydrogen consumption[10]

Hydrogen serves as a versatile fuel for fuel cell applications, producing power with zero harmful pollutants, improving public health, and significantly reducing greenhouse gas (GHG) emissions that drive climate change[11]. They avoid emitting harmful air pollutants that contribute to smog and health risks and their near-silent operation makes them an exceptionally clean and quiet energy solution[12]. Currently, companies like Siemens and General Electric offer hydrogen-powered internal combustion engine generators, with existing systems reaching up to 1 MW in power output. For larger-scale applications, hydrogen gas turbines can achieve significantly higher capacities—ranging from 20 to 30 MW. Leading turbine manufacturers, such as Siemens, Mitsubishi, and Kawasaki, are actively developing and testing hydrogen-powered turbines for integration into electric grids[13].

II. METHODOLOGY

A. *The Thermal Power Plant Description*

In this study, Egbin Thermal Power Plant (a steam turbine plant) located in Ijede, Lagos State, Nigeria was chosen as the potential site for integrating the waste-to-hydrogen technology. This is due to its compliance with the following integration criteria[7]:

1 It can supply steam with the necessary specifications for oxidation of carbon monoxide.
2 It is easily accessed by road and also close to Lagos lagoon for the transportation of MSW and the produced hydrogen.
3 There is sufficient free space for the construction of MSW gasification and hydrogen production complex.
4 The location of the STP meets the standard distance regulations for safety and operational effectiveness.
5 There is availability of liquid fuel reserves for substitution requirements.

Egbin Power Plant, Nigeria's largest electricity generation facility, has an installed capacity of 1,320 megawatts (MW), distributed across six units, each generating 220 MW, serving as a critical component of the national grid[14]. Unit 1 designated as K-220-12.5/50 was chosen as the site for integrating the waste-to-hydrogen technology. The steam turbine plant's established infrastructure and its critical role in Nigeria's power grid system position it as a prime location for exploring innovative and advanced energy technologies. Operating on a regenerative Rankine cycle, the system features:

- A natural gas-fired boiler system (with economizer, evaporator, superheater, and reheater sections)
- Multi-stage turbine assembly (HPT, IPT, LPT)
- Comprehensive feedwater heating system (2 HP heaters, 3 LP heaters, deaerator, drain cooler)
- Secondary HFO fuel capability

The thermodynamic cycle begins with 236.6°C feedwater pressurized to 12.5 MPa, generating 538°C superheated steam. Steam expands through turbine stages with intermediate reheating (538°C), while extraction steam feeds the regenerative heating system. Condenser cooling utilizes lagoon water, completing the energy cycle[15],[16]. The design-nominal parameters of the plant is shown in table I below.

TABLE I
EGBIN STEAM TURBINE PLANT UNIT 1 DESIGN-NOMINAL PARAMETERS [16]

	G (t/h)	T (°C)	Y	P (kg/cm2)
Live steam from boiler to HPC	647.5	538	0	125
Reheat steam from boiler to IPC	579.7	538	0	30.76
Steam inlet to LPC	537.2	332.2	0	6.94
Exhaust steam to condenser	459.2	-	0.08	0.085
Condensate output from condenser	540.9	42.6	1	0.085
GLC condensate output	540.9	43.1	1	11.5
Drain Cooler condensate output	540.9	49.58	1	11.5
LPH-1 condensate output	540.9	86.7	1	11.5
LPH-2 condensate output	540.9	110	1	11.5
LPH-3 condensate output	540.9	134.2	1	11.5
Deaerator feed water output	647.5	163	1	6.664
Feed Water Pump output	647.5	165	1	137.5
HPH-4 feed water output	627.5	196.6	1	137.5
HPH-5 feed water output	627.5	236.6	1	137.5
Cooling water inlet	32660	30	1	1
Cooling water outlet	32660	36	1	1
Generator capacity	220 MW			

B. Modelling of the Steam Turbine Plant

To develop a simulation model of Egbin Steam Turbine Plant unit 1, CAD united cycle simulation software was utilized. The simulation platform enables comprehensive modeling of thermal power plant operations across all configurations. Its three-phase analytical approach includes:

- Thermodynamic Model Development: Automated generation of mathematical models through thermal circuit construction
- System Parameter Definition: Configuration of operational parameters using baseline plant data to establish model coefficients
- Operational Simulation: Execution of performance calculations under specified operating conditions

The system accommodates both design-specified and empirically-derived operational baselines, ensuring accurate representation of physical plant characteristics across various operational scenarios[6]. The simulation model of Egbin steam turbine plant unit 1 (K-220-12.5/50) is shown in fig. 4 below.

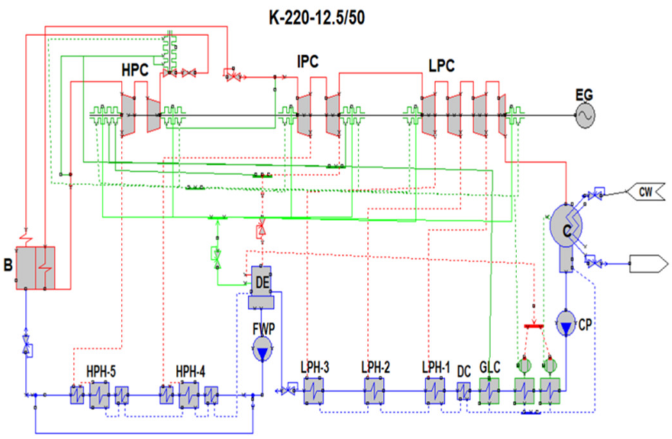

Fig. 4 Simulation model of Egbin STP unit 1 (k-220-12.5/50)

B – Boiler; HPC – High-pressure cylinder; IPC – Intermediate-pressure cylinder; LPC – Low-pressure cylinder; EG – Electric generator; CW – Circulating water; CP – Condensate pump; AE – Air ejector; GLC – Gland leakage condenser; DC – Drain cooler; LPH – Low-pressure heater; HPH – High-pressure heater; DE – Deaerator; FWP – Feed water pump; C – Condenser

C. Adequacy

Adequacy assessment involves comparative analysis between the model's output data and the reference design parameters (Table I) for the specified operational mode. The model demonstrated high accuracy with an average deviation of just 0.35% as shown in Table II below, confirming its reliability and practical suitability.

TABLE II
COMPARISON OF THE SIMULATION DATA WITH THE DESIGN PARAMETERS OF THE STP

	Design data	Model data	Deviation (%)
Generator output, MW	220	222.95	1.34
Live steam flow-rate, t/h	647.5	647.5	0
Live steam temperature, °C	538	538	0
Live steam pressure, kg/cm2	125	125	0
Reheat steam flow-rate, t/h	579.7	579.7	0
Reheat steam temperature, °C	538	538	0
Reheat steam pressure, kg/cm2	30.76	30.71	0.16
LPC inlet steam flow-rate, t/h	537.2	537.2	0
LPC inlet steam temperature, °C	332.2	330.9	0.39
LPC inlet steam pressure, kg/cm2	6.94	6.93	0.14
Exhaust steam flow-rate, t/h	459.2	459.6	0.08
Exhaust steam wetness fraction	0.08	0.08	0
Condenser pressure, kg/cm2	0.085	0.085	0
Condensate flow-rate, t/h	540.9	539.6	0.24
Condensate temperature in condenser, °C	42.6	42.4	0.46
CP output pressure, kg/cm2	11.5	11.5	0
GLC condensate output temperature, °C	43.1	43.97	2.0
DC condensate output temperature, °C	49.58	51.4	3.6
LPH-1 condensate output temperature, °C	86.7	86.9	0.23
LPH-2 condensate output temperature, °C	110	109.3	0.63
LPH-3 condensate output temperature, °C	134.2	133.8	0.29
Deaerator pressure, kg/cm2	6.664	6.664	0
Deaerator Feed water flow-rate, t/h	647.5	646.8	0.1
Deaerator feed water temperature, °C	163	162.2	0.49
FWP output pressure, kg/cm2	137.5	137.5	0
FWP output temperature, °C	165	164	0.6
HPH-4 feed water output flow-rate, t/h	627.5	626.8	0.1
HPH-4 feed water output temperature, °C	196.6	196.32	0.14
HPH-5 feed water output temperature, °C	236.6	236.6	0
Cooling water inlet temperature, °C	30	30	0
Cooling water outlet temperature, °C	36	36	0
Average deviation, %			0.35

The efficiency of the STP power output is given as;

$$\eta_{th} = \frac{N - N^{OWN}}{Q_0} \times 100\ ,\%$$

(1)

Where η_{th} = efficiency of STP power output , %
N = STP gross electrical power output , MW
N^{OWN} = STP electrical power consumed for own needs , MW
Q_0 = boiler heat rate , MW

The STP reference fuel consumption is given as;

$$G_{ref.f.} = \frac{3.6 \times Q_0}{Q^n_{CV.ref.f.} \times \eta_B}\ ,t\ ref.f./h$$

(2)

Where $G_{ref.f.}$ = STP reference fuel consumption ,t ref. f./h
$Q^n_{CV.ref.f.}$ = net calorific value of reference fuel $(29.31 \frac{MJ}{kg} ref.f.)$ [17]
η_B = boiler efficiency = 0.90 – 0.95 [16] (0.93 is assumed)

The STP specific reference fuel consumption is given as;

$$G^{sp}_{ref.f.} = \frac{G_{ref.f.}}{N - N^{OWN}}\ ,t\ ref.f./MWh$$

(3)

Where
$G^{sp}_{ref.f.}$ = specific reference fuel consumption , t ref. f./MWh

D. Evaluation of the Potential Hydrogen Yield by Gasification of Municipal Solid Waste

The solid waste generated in Lagos State, Nigeria, which is also the city where the Egbin thermal power plant is situated, is being considered in this study. Lagos State generates 14,000 tons of solid waste in a day with 70% dumped in government approved dumpsites and 30% dumped at illegal dumpsites [18].

$G_{MSW} = 14{,}000\ \frac{t}{d} = 584\ t/h$
(4)
Where G_{MSW} = amount of MSW generated per hour

The MSW generated is converted to RDF for gasification by firstly classifying and sorting them to separate recyclable materials based on their properties. Combustible wastes like plastics, waste paper, wood chips, and PVC are isolated, then crushed, dried, and ground into granular fuels. The resulting RDF fuel is chalk-shaped, measuring 15-20mm in diameter and 30-50mm in length, with a moisture content of less than 12% and a calorific value similar to coal (14,595-20,016 kJ/kg). This fuel is suitable for waste-to-energy plants, cement plants, and various industrial boilers. Key equipment used in the production includes magnetic separators, air sorters, screening equipment, pre-shredders, secondary shredders, and RDF forming machines [19].

During municipal solid waste (MSW) gasification, synthesis gas (syngas) which comprises carbon monoxide (CO) and hydrogen (H2) mixture is generated. The syngas is then processed further to separate hydrogen, similar to the steam reforming of methane. Constituents of the syngas varies due to diverse morphological characteristics of the waste, resulting in hydrogen volume percentages ranging from 25% to 75%. To enhance hydrogen production, CO is further oxidized to carbon dioxide (CO2) by introducing steam, followed by capturing CO2 using pressure swing adsorption (PSA) as shown in fig. 5 below. This method increases the hydrogen concentration in the gas[7]. The oxidation of CO by steam for hydrogen production is known as water-gas shift reaction, and from a thermodynamic perspective, low-temperature ranges (150 - 500℃) favor high hydrogen selectivity due to the exothermic reaction characteristics with pressure having no impact[20],[21].

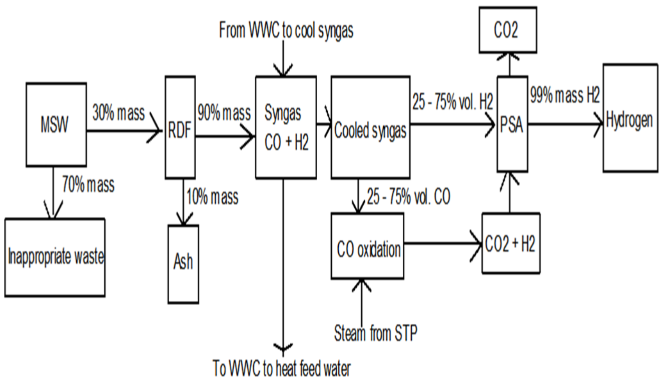

Fig. 5 Flow diagram for hydrogen production via MSW gasification

MSW – Municipal solid waste; RDF – Refuse derived fuel; CO – Carbon monoxide; H2 – Hydrogen; CO2 – Carbon dioxide; WWC – Water-water gas cooler; STP – Steam turbine plant

Assuming 30% of the generated MSW is converted to refuse derived fuel (RDF)[7]

$G_{RDF} = 0.3 \times G_{MSW} = 175\ t/h$
(5)
Where G_{RDF} = amount of RDF gotten from MSW , t/h

The RDF enters the gasifier with circulating fluidized bed where it is gasified to yield synthesis gas (mixture of hydrogen and CO) and ash.

Assuming 10% of the RDF is converted to ash after gasification[22]

$G_{SG} = 0.9 \times G_{RDF} = 158\ t/h$
(6)
Where G_{SG} = synthesis gas flow − rate , t/h

Due to morphological content of the processed MSW, the volumetric hydrogen concentration in the produced synthesis gas varies from 25 – 75% [22]. In this work, 25, 35, 45, 55, 65 and 75% will be analyzed.

Having known the hydrogen and CO volumetric fraction in synthesis gas, the mass fraction can be determined as follows

$m_H = \frac{v_H \times \rho_H}{(v_H \times \rho_H) + (v_{CO} \times \rho_{CO})}$
(7a)
and
$m_{CO} = 1 - m_h$
(7b)
where
m_H = mass fraction of hydrogen in the synthesis gas
m_{CO} = mass fraction of CO in the synthesis gas
v_H = volume fraction of hydrogen in SG (25, 35, 45, 55, 65, 75)%
ρ_H = density of hydrogen $(0.02185\ \frac{kg}{m^3})$ [22]
v_{CO} = volumetric fraction of CO in SG which is $(1 - v_H)$

ρ_{CO} = density of carbon monoxide, CO $\left(0.304\frac{kg}{m^3}\right)$ [22]

Hydrogen mass content in synthesis gas is given as;

$$G_H^{SC} = m_H \times G_{SG}, t/h$$
(8a)

And

$$G_{CO} = G_{SG} - G_H^{SC}, t/h$$
(8b)

where G_H^{SC} = hydrogen mass content in synthesis gas

G_{CO} = carbon monoxide mass content in the synthesis gas

Following the gasification process at 850°C, the formed syngas is cooled to 450°C to comply with process specifications and inhibit the generation of NO_2 and other nitrogen oxides (NOx). The cooling process enables alkalis and heavy metals in gaseous form to condense into solid particles. Additionally, the recovered thermal energy is utilized to preheat boiler feed water. This is achieved by integrating water-water synthesis gas cooler (WWC)[7].

The rate of heat extraction from the syngas to cool it is calculated as follows;

$$Q_{SG} = \overline{C_{SG}} \times G_{SG} \times (t_g - t_{SG}) = C_{p\,cw} \times G_{cw} \times (t_2 - t_1), W$$
(9a)

and

$$\overline{C_{SG}} = (m_H \times C_H) + (m_{CO} \times C_{CO}), J/kgK$$
(9b)

Where

Q_{SG} = heat extraction rate to cool the synthesis gas, MW

$\overline{C_{SG}}$ = average heat capacity of synthesis gas, J/kgK

C_H = average heat capacity of hydrogen $\left(14.55\frac{kJ}{kgK}\right)$ [22]

C_{CO} = average heat capacity of CO $\left(1.08\frac{kJ}{kgK}\right)$ [22]

t_g = temperature of the gasification process (850°C) [22]

t_{SG} = cooled synthesis gas temperature (450°C) [22]

$C_{p\,cw}$ = cooling water heat capacity $\left(4.19\frac{kJ}{kgK}\right)$ [22]

G_{cw} = cooling water mass flow-rate, kg/s

t_2 = cooling water temperature at gas cooler outlet, °C

t_1 = cooling water temperature at gas cooler inlet, °C

Following the cooling process, the toxic carbon monoxide present in the syngas undergoes steam oxidation using turbine-extracted steam, producing carbon dioxide and generating supplemental hydrogen. The resulting chemical transformation can be represented as;

$$CO + H_2O \rightarrow CO_2 + H_2$$

Based on molar mass calculations for the oxidation of 1 gram of CO:

The reaction yields 0.071 g hydrogen

The reaction produces 1.57 g carbon dioxide

The reaction consumes 0.642 g steam.

$$1gCO + 0.642gH_2O \rightarrow 1.57gCO_2 + 0.071gH_2$$

This implies that;

$$G_{H_2O} = 0.642 \times G_{CO}, t/h$$
(10a)

$$G_{CO_2} = 1.57 \times G_{CO}, t/h$$
(10b)

$$G_H^{CO} = 0.071 \times G_{CO}, t/h$$
(10c)

Where

G_{H_2O} = steam consumption required for CO oxidation, t/h

G_{CO_2} = amount of CO_2 produced after CO oxidation, t/h

G_H^{CO} = amont of hydrogen produced from CO oxidation, t/h

Following the CO-to-CO_2 conversion, the resulting carbon dioxide is isolated through Pressure Swing Adsorption technology. The PSA system achieves a hydrogen recovery efficiency of 99% from the gas mixture[22]. Then the total hydrogen yield from MSW will be;

$$G_H = \delta_H \times (G_H^{SC} + G_H^{CO}), t/h$$
(11)

Where

G_H = total amount of hydrogen generated from MSW, t/h

δ_H = fraction of hydrogen extracted from mixture using PSA (0.99assumed)[22]

$(G_H^{SC} + G_H^{CO})$ = hydrogen flow-rate in the mixture after CO oxidation t/h

E. Modelling of the Cogeneration Power Plant

The Egbin TPP comprises of six steam turbine units equipped with K-220-12.5/50 turbines. The first steam power unit is being integrated with a hydrogen production complex. The novel configuration modifies conventional steam-power systems by routing a portion of the deaerated feedwater through a water-cooled syngas heat exchanger before entering the power boiler. The heat exchanger utilizes thermal energy from the syngas cooling loop to elevate the water temperature. The system design incorporates steam extraction from the intermediate-pressure turbine stage to support the syngas post-oxidation process.

There is also an increase in boiler steam consumption to compensate for the steam withdrawn for CO oxidation, thereby keeping the STP's power output constant[22].

Fig. 6 presents the upgraded thermal model of the TPP after integrating hydrogen production unit, developed using CAD united cycle simulation software.

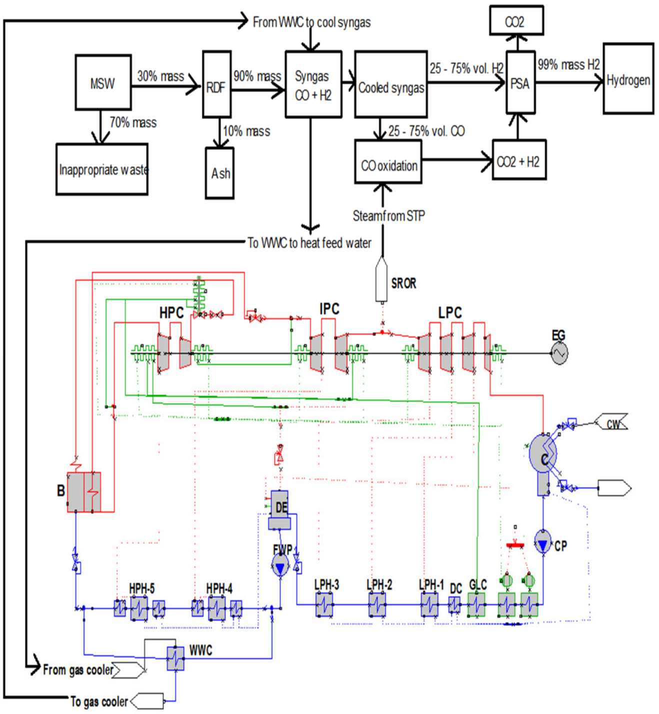

Fig. 6 Simulation model of the cogeneration thermal power plant

B – Boiler; HPC – High-pressure cylinder; IPC – Intermediate-pressure cylinder; LPC – Low-pressure cylinder; EG – Electric generator; CW – Circulating water; CP – Condensate pump; AE – Air ejector; GLC – Gland leakage condenser; DC – Drain cooler; LPH – Low-pressure heater; HPH – High-pressure heater; DE – Deaerator; FWP – Feed water pump; MSW – Municipal solid waste; RDF – Refuse derived fuel; CO – Carbon monoxide; H2 – Hydrogen; CO2 – Carbon dioxide; WWC – Water-water gas cooler; STP – Steam turbine plant; SROR – Steam extracted for oxidation reaction

The efficiency of the cogeneration plant is assessed using Fuel Heat Utilization Factor which is given as;

$$FHUF = \frac{(N - N^{OWN}) + Q_H}{Q_O + Q_{SC}} \times 100 \text{ , \%}$$

(12a)

And

$$Q_H = G_{H_2O} \times h_{H_2O} \text{ , MW}$$

(12b)

Where $FHUF$ = fuel heat utilization factor , %

Q_H = heat rate for hydrogen production , MW

Q_O = cogeneration TPP boiler heat rate , MW

Q_{SC} = rate of heat release from synthesis gas to heat feed water , MW

Q_N = heat rate for electricity generation , MW

G_{H_2O} = steam consumption required for CO oxidation , kg/s

h_{H_2O} = enthalpy of steam required for CO oxidation , MJ/kg

Reference fuel consumption of the cogeneration plant is given as;

$$B = \frac{3.6 \times Q_O}{Q^n_{CV.ref.f.} \times \eta_B} \text{ , t ref. f./h}$$

(13)

Where

B = cogeneration plant reference fuel consumption , t ref. f./h

$Q^n_{CV.ref.f.}$ = net calorific value of reference fuel ($29.31 \frac{MJ}{kg}$ ref. f.)

[17]

η_B = boiler efficiency

III. RESULTS AND DISCUSSION

F. Calculated Result of the Main Parameters for Initial Operating Mode of the Steam Turbine Power Plant

The simulation model of Egbin Steam Thermal Power Plant unit 1 was done using CAD united cycle simulation software as shown in fig. 4 above. The basic mode of operation which is the design-nominal mode of operation was developed using the design element characteristics of the TPP as shown in Table I above.

Adequacy assessment which involves comparative analysis between the model's output data and the reference design parameters (Table I) for the specified operational mode was carried out as shown in Table II above. The model demonstrated high accuracy with an average deviation of just 0.35%, confirming its reliability and practical suitability.

The calculated result of the main parameters for initial operating mode of the STP is shown in table III below.

TABLE III
CALCULATED RESULT OF THE MAIN PARAMETERS FOR INITIAL OPERATING MODE OF THE STP

N (MW)	N^{OWN} (MW)	Q_N (MW)	η_{th} (%)	$G_{ref.f.}$ (t ref. f./h)	$G^{sp}_{ref.f.}$ (t ref. f./MWh)
222.95	2.91	507.3	43.37	67	0.304

G. Estimated Result of the Potential Hydrogen Yield by Gasification of Lagos' Municipal Solid Waste

The calculated result of the total estimated hydrogen yield by gasification of Lagos' municipal solid waste is shown in table IV below

TABLE IV
TOTAL ESTIMATED HYDROGEN YIELD BY GASIFICATION OF LAGOS' MUNICIPAL SOLID WASTE

v_H (%)	G_{MSW} (t/h)	G_{RDF} (t/h)	G_{SG} (t/h)	G_H^{SG} (t/h)	G_H^{CO} (t/h)	Q_{SG} MW	G_{H_2O} (t/h)	G_H (t/h)
25				3.7	11	24.5	99	14.6
35	584	175	158	5.9	10.8	27.8	97.6	16.5
45				8.8	10.6	32.1	95.8	19.2
55				12.8	10.3	38.1	93.2	22.9
65				18.6	9.9	46.8	89.5	28.2
75				28	9.2	60.9	83.5	36.8

Table IV above shows that the integrated hydrogen production unit can process the 14,000 tons per day Lagos' municipal solid waste to produce 14.6 t/h, 16.5 t/h, 19.2 t/h, 22.9 t/h, 28.2 t/h and 36.8 t/h of hydrogen at 25%, 35%, 45%, 55%, 65% and 75% volumetric hydrogen concentration in synthesis gas respectively by gasification method using pressure swing adsorption for purification.

The effect of MSW morphological content on total hydrogen yield, rate of heat removal from synthesis gas and steam extracted to oxidize CO is shown in fig. 7 below

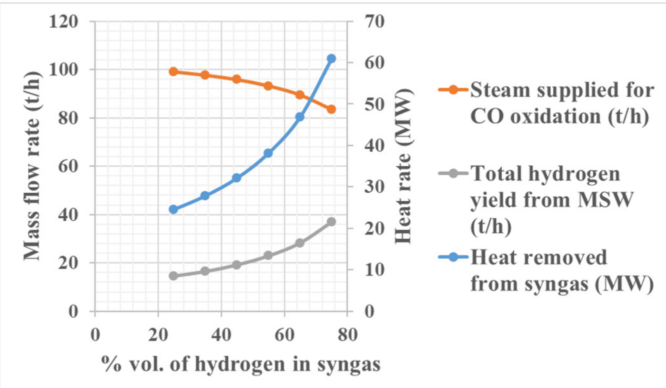

Fig. 7 Effect of MSW morphological content on hydrogen yield, rate of heat removal from synthesis gas and steam extracted to oxidize CO

Fig. 7 above reveals that the morphological content of municipal solid waste (MSW) significantly influences total hydrogen yield, rate of heat removal from synthesis gas and steam extracted to oxidize CO. The total hydrogen yield increased from 14.6 t/h to 36.8 t/h (a 22.2 t/h increment) as the volumetric hydrogen concentration in syngas rose from 25% to 75%. Concurrently, the amount of steam extracted for carbon monoxide oxidation decreased from 99 t/h to 83.5 t/h (a 15.5 t/h reduction); while the rate of heat removal from synthesis gas for its cooling increased from 24.5 MW to 60.9 MW (a 36.4 MW increment), all indicating the significant effect of the morphological content of the processed MSW on total hydrogen yield, rate of heat removal from synthesis gas and steam extracted to oxidize carbon monoxide.

H. Energy Effect of the Integrated Scheme of Hydrogen Production Unit on the Main Parameters and Indexes of the STP

Table V below shows the calculated key parameters and indexes of the STP before and after integrating the hydrogen production system into the STP's thermal scheme.

TABLE V
CALCULATED KEY PARAMETERS AND INDEXES OF THE STP BEFORE AND AFTER INTEGRATING THE HYDROGEN PRODUCTION SYSTEM INTO THE STP'S THERMAL SCHEME

Parameter	Initial model	Cogeneration model					
		v_H (%)					
		25	**35**	**45**	**55**	**65**	**75**
N (MW)	222.95						
Q_0 **(MW) with WWC switched-off**	507.3	535.44	535.08	534.62	533.96	533.00	531.44
Q_0 **(MW) with WWC switched-on**	507.3	506.60	502.34	497.23	489.69	478.82	461.76
FHUF (%) with WWC switched-off	43.37	56.95	56.76	\ 56.53	56.18	55.70	54.90
FHUF (%) with WWC	43.37	57.41	57.29	57.09	56.84	56.48	55.83

switched-on							
B (t ref. f./h With WWC switched-off	67	70.72	70.67	70.61	70.52	70.39	70.19
B (t ref. f./h With WWC switched-on	67	66.91	66.34	65.67	64.67	63.24	60.98

Fig. 8 below shows the graph of volumetric hydrogen concentration in synthesis gas versus boiler heat rate of the cogeneration plant

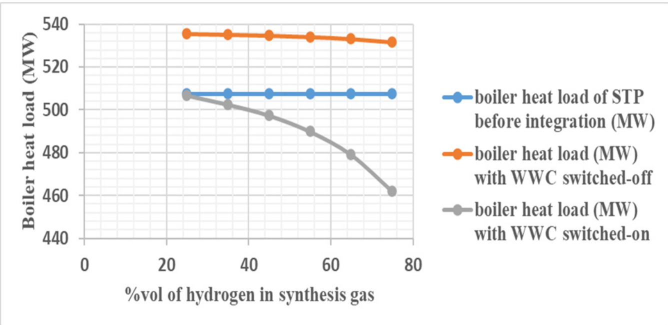

Fig. 8 Volumetric hydrogen concentration in synthesis gas versus boiler heat rate

From fig. 8 above, boiler heat rate of the cogeneration TPP decreased significantly from 506.6 MW to 461.76 MW (a 44.84 MW reduction) when WWC is switched on as the volumetric hydrogen concentration in synthesis gas rose from 25% to 75%; however, when WWC is switched off, boiler heat rate only decreased from 535.44 MW to 531.44 MW (a 4 MW reduction), demonstrating a negligible effect of morphological content of processed MSW on boiler heat rate when WWC is switched-off compared to when it is activated.

Also, boiler heat rate of the STP after integrating the MSW-to-hydrogen unit showed contrasting effects based on the operational status of the WWC: with the WWC switched on, heat rate decreased from 507.3 MW to 461.76 MW (a 45.54 MW reduction) at 75% volumetric hydrogen concentration in synthesis gas, indicating a positive effect; however, with the WWC switched off, the heat rate increased from 507.3 MW to 531.44 MW (a 24.14 MW increment), reflecting a negative effect.

The graph of volumetric hydrogen concentration in synthesis gas versus FHUF of the cogeneration plant is shown in fig. 9 below

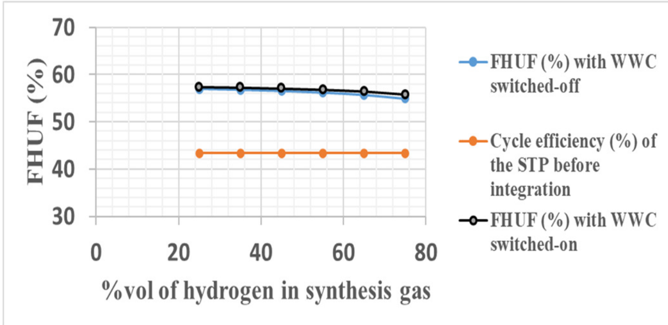

Fig. 9 Volumetric hydrogen concentration in synthesis gas versus FHUF

From fig. 9 above, Fuel Heat Utilization Factor (FHUF) of the cogeneration TPP showed a slight decrease as the volumetric hydrogen concentration in synthesis gas increased from 25% to 75%: with the WWC switched on, FHUF decreased from 57.41% to 55.83% (2.75% reduction), while with the WWC switched off, it decreased from 56.95% to 54.90% (3.6% reduction), indicating a negligible effect of morphological content of processed MSW on FHUF in both WWC operational status.

Also, the STP's Fuel Heat Utilization Factor (FHUF) after integrating MSW-to-hydrogen unit showed significant positive effects in both operational states of the WWC: with the WWC switched on, FHUF at 25% volumetric hydrogen concentration in synthesis gas increased from 43.37% to 57.41% (32.37% increment), while with the WWC switched off, it increased from 43.37% to 56.95% (31.31% increment), indicating a positive impact of the integration on the FHUF of the STP; however, the difference in FHUF of the cogeneration TPP at 75% hydrogen volumetric content in synthesis gas between the WWC switched on (55.83%) and WWC switched off (54.90%) is only 0.93%, suggesting a negligible effect of the WWC operational status on FHUF of the cogeneration TPP.

The graph of volumetric hydrogen concentration in synthesis gas versus reference fuel consumption of the cogeneration plant is shown in fig. 10 below

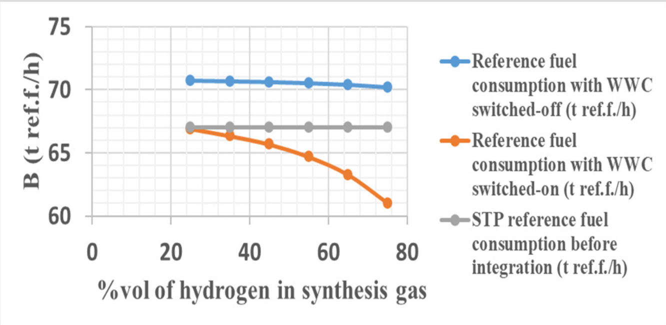

Fig. 10 Volumetric hydrogen concentration in synthesis gas versus reference fuel consumption

From fig. 10 above, reference fuel consumption of the cogeneration TPP when WWC is switched-on decreased significantly from 66.91 t ref.f./h to 60.98 t ref.f./h (a 5.93 t ref.f./h reduction) as the volumetric hydrogen concentration in synthesis gas rose from 25% to 75%; however, with the WWC switched off, reference fuel consumption only decreased from 70.72 t ref.f./h to 70.19 t ref.f./h (a 0.53 t ref.f./h reduction), reflecting a negligible effect of morphological content on reference fuel consumption when WWC is switched-off compared to when WWC is activated.

Also, reference fuel consumption of the STP after integrating the MSW-to-hydrogen unit showed contrasting effects based on the operational status of the WWC: with the WWC switched on, it decreased from 67 t ref.f./h to 60.98 t ref.f./h (a 6.02 t ref.f./h reduction) at 75% volumetric hydrogen concentration in synthesis gas, indicating a positive effect; however, with the WWC switched-off, reference fuel consumption increased from 67 t ref.f./h to 70.19 t ref.f./h (a 3.19 t ref.f./h increment), reflecting a negative effect.

IV. CONCLUSION

The study successfully validated an approach for hydrogen production through MSW gasification by integrating hydrogen generation unit into operational thermal power plant. A novel thermal scheme which involves an integrated system of a steam turbine plant and a hydrogen production unit has been developed. The effect of MSW morphological content on the various aspects of gasification process and the newly developed cogeneration thermal scheme was assessed. The energy effect of the transfer of the TPP from condensing steam turbine plant to a cogeneration power plant was also assessed taking into account the operational status of WWC. From the results obtained, the following conclusions can be asserted:

- The integrated hydrogen production unit can process the 14,000 tons per day Lagos' municipal solid waste to produce 14.6 t/h, 16.5 t/h, 19.2 t/h, 22.9 t/h, 28.2 t/h and 36.8 t/h of hydrogen at 25%, 35%, 45%, 55%, 65% and 75% volumetric hydrogen concentration in synthesis gas respectively by gasification method using pressure swing adsorption for purification.
- Morphological content of the processed municipal solid waste (MSW) significantly influences total hydrogen yield, rate of heat removal from synthesis gas and steam extracted to oxidize CO.
- The boiler heat rate of the STP after integrating hydrogen production unit with WWC switched-on decreased from 507.3 MW to 461.76 MW (45.54 MW reduction or 8.98% decrease) at 75% volumetric hydrogen concentration in synthesis gas but increased from 507.3 MW to 531.44 MW (24.14 MW increment or 4.76% increase) with WWC switched off; indicating a positive effect of the integration process on boiler heat rate of the STP when WWC is switched-on and a negative effect when WWC is switched-off.
- The FHUF of the STP after integrating hydrogen production unit increased from 43.37% to 57.41% (32.37% increase) with WWC switched-on and from 43.37% to 56.95% (31.31% increase) with WWC switched off at 25% volumetric hydrogen concentration in synthesis gas; indicating a significant positive effect of the integration process on FHUF of the STP irrespective of the operational status of WWC.
- The reference fuel consumption of the STP after integrating hydrogen production unit with WWC switched-on decreased from 67 t ref.f./h to 60.98 t ref.f./h (6.02 t ref.f./h reduction or 8.99% decrease) at 75% volumetric hydrogen concentration in synthesis gas but increased from 67 t ref.f./h

to 70.19 t ref.f./h (3.19 t ref.f./h increment or 4.76% increase) with WWC switched off; indicating a positive effect of the integration process on reference fuel consumption of the STP when WWC is switched-on and a negative effect when WWC is switched-off.
- Irrespective of morphological content of the processed MSW, integrating hydrogen production unit into an existing TPP has a positive energy effect on the TPP operations.

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